Economic Issues in Using FGD By-Product in Agricultural Gypsum Markets

by

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ABSTRACT

Flue gas desulfurization (FGD), can produce gypsum (calcium sulfate) which is potentially useful as a substitute for agricultural and crude gypsum. Moreover, forced oxidation is an advanced method in producing high quality FGD by-product gypsum that competes for use in wallboard and construction. The present paper is an analysis of market forces of demand and supply of agricultural gypsum. The objective is to provide perspective on the potential use in agriculture of the FGD by-product gypsum generated from coal combustion.

The result of the econometric analysis shows that demand for agricultural gypsum is inelastic (0.013) indicating a relatively stable demand. A 1 percent change in agricultural gypsum price hardly affects its demand by farmers (0.013 percent change). On the other hand, supply of agricultural gypsum proves to be elastic and positively related to its price.

FGD by-product gypsum would be entering a highly competitive market. Its use in agriculture would increase agricultural gypsum supplies, lower agricultural gypsum price, but have little effect on agricultural gypsum use. Other uses, such as wallboard and construction, likely offer more promising market potential than does agriculture.

Glossary

FGD gypsum:
gypsum generated from processed (oxidation of) FGD by-products.

By-product gypsum (or agricultural gypsum):
a class of gypsum by-products that includes FGD gypsum and natural gypsum by-products.

Nonphosphogypsum:
by-product produced from non mined gypsum. It includes all kinds of by-products that generate gypsum via processing (e.g. FGD gypsum).

Phosphogypsum:
mined (natural) gypsum.

PART I

Introduction

The United States's total annual production of coal combustion by-products is estimated to reach 120 million tons by the year 2000. The United States's clean-air laws impose the need to reduce sulfur emission from high sulfur coal combustion in generating electricity. The sulfur dioxide control at the power plants generates large amounts of by-products. Flue gas desulfurization (FGD) by-products result from the new environmental regulations and the quality and amounts produced vary with the source and type of coal utilized, the type of scrubber used, and power plant design (Makansi).

Clean Air Act

Utilities have several options to meet the Clean Air Act requirement. Some of these options include the installment of scrubbers to reduce emissions, the consumption of low-sulfur coals, a switch to a completely different fuel, or the purchase of pollution credits from other utilities. Starting from the year 2000, Phase II will cause a switch to low sulfur coal. Low-sulfur mines in central Appalachia and the West will benefit from this policy. High market demand for low-sulfur coal is expected to bid its price up and probably increase imports significantly under Phase II. The estimated demand for low-sulfur foreign coal is 8.5 million tons (Belsie).

Gypsum-producing FGD by-products

Flue gas desulfurization (FGD) processes are generally classified as either wet or dry system, depending on the end by-product created. Major differences between the two methods are the SO_2 (sulfur dioxide) removal efficiency from the flue gases and the moisture condition of the waste products. The wet scrubbing systems generally have greater than 90 percent SO_2 removal efficiencies compared to 70 percent for the dry systems. The wet systems are most likely preferred by the majority of utilities. An advantage of the wet scrubbing processes is the generation of by-product gypsum (wallboard quality). However, the wet scrubbing processes produce nearly twice as much by-product as the dry processes.

The economics of FGD-by product utilization instead of disposal has been emphasized as the cost of landfilling has increased due to limited land availability and environmental regulations (Steffan et al). The reaction between SO_2 and lime initially produces calcium sulfite. Using forced oxidation, sulfite transforms to calcium sulfate[1] (or gypsum slurries). Calcium sulfate is easier to dewater than the calcium sulfite sludge. It may be disposed of in landfills, sold to U.S. wallboard and cement manufactures, or may be suitable for use in agriculture (Mineral Summaries, 1991). One advantage of FGD by-product gypsum materials is their typically finer particle size as opposed to mined gypsum, which may usually be crushed to different particle sizes depending on the use. The finer quality increases the dissolution rate and the effectiveness of gypsum amendment.

Utilization potential of FGD sludge

By-product gypsum can be substituted for crude gypsum in agriculture and is in fact being preferred to crude gypsum for cement set-retarding and manufacturing wallboard (Korcak). Lime or pulverized limestone FGD scrubbing systems produce large amounts of potentially useful by-product gypsum, of which only a small amount is being recovered (Korcak).

Comparison Between U.S. and Foreign Experiences

The gypsum-producing FGD systems used in Europe and Japan are technologically advanced systems. In Japan, emphasis on gypsum-producing FGD systems is caused by the shortage of natural gypsum reserves. Many limestone and lime FGD technologies produce gypsum by the forced oxidation method and the by-product FGD gypsum can be sold to the wallboard and cement industries (Mineral Summaries, 1991).

In Germany, the potential use of by-product gypsum is primarily in the building industry. FGD gypsum is mixed with proprietary additives, pressed into forms, and heated with steam in an autoclave for seven hours. The

[1]Calcium sulfate dihydrate or gypsum ($CaSO_4 2H_2O$) is produced by forced oxidation of calcium sulfate hemihydrate in the scrubber. Calcium sulfite hemihydrate, ($CaSO_3 \frac{1}{2} H_2O$), is the initial by-product generated in calcium based FGD scrubbing system (2).

resulting alpha-hemihydrate product is used in the building industry (Steffan et al).

In the United States, power plants have favored the wet FGD processes. For the most part, the designs can be characterized as somewhere between the FGD systems installed earlier in the U.S. and the more recent advanced systems now operating in Europe and Japan. Noting that most U.S. FGD systems will handle coals with much higher sulfur contents than their overseas counterparts, this trend should not be surprising (Belsie). Almost all limestone units in the U.S. will operate in a forced-oxidation mode to produce gypsum that is generally suitable for many disposal options. The United States' production of byproduct gypsum from coal combustion in generating electricity could feed the wallboard industry if more attention is given to advanced processing and if the cost of advanced processing is more efficient in producing wallboard compared to that produced from natural gypsum.

Table 1 illustrates current and projected amounts of by-products produces by coal combustion. In 1985, FGD by-products reached 16 million tons (EPA, 1988). By the year 2000, the estimated FGD production will generate up to 50 million tons of wastes annually.

Gypsum Industry in the U.S.

The United States is the world's leading producer of gypsum. In 1991, gypsum production accounted for 15 percent of the total world production. U.S. gypsum industry is dominated by a few large "vertically integrated" companies that mine and calcine[2] gypsum as well as manufacture plaster and wallboard products.

Crude gypsum is primarily mined for the manufacture of gypsum wallboard and plaster. In 1991, gypsum was mined by 32 companies at 61 mines in twenty states and calcined by 13 companies at 71 plants in 28 states. By-product gypsum is mostly used in agriculture and smaller amounts in the manufacture of wallboard. Total production of by-product gypsum reached 681,000 tons in

[2]Calcined gypsum or dehydrated gypsum, $CaSO_4 \frac{1}{2} H_2O$, is calcium sulfate dihydrate (crude, crushed or ground gypsum) heated to about 350° F. In the process, hydrated gypsum loses three fourth of its water content. The calcined gypsum can be transformed into different products by adding a retarder or an accelerator in mixture.

1991 of which 78 percent was of nonphosphogypsum origin (origin other than mined gypsum). The use of by-product gypsum derived from nonphosphogypsum is increasing (78 percent in 1991 as compared to 69 percent in 1990) (Davis).

The U.S. gypsum consumption is defined as the sum of U.S. production, net imports, and the industry stock change. In 1991, 33 percent of crude gypsum consumption was imported. Crude gypsum from Canada and Mexico was mainly used in wallboard manufacturing in coastal cities. On the other hand, crude gypsum imported from Spain was used in portland cement manufacturing. Wallboard exports in 1991 were equivalent to 74,000 short tons. In 1990, exports accounted for 75 million square feet to 42 countries. This export amount was 29 percent lower than that of 1989.

The United States demand for gypsum is expected to follow an increasing trend. The expected consumption rate of gypsum for the year 2000 is between 26 and 56 million tons with a probable demand of 35 million tons (Reed).

Gypsum reserves are distributed unequally over the United States. The Great Lakes region, midcontinent region, California, and some other states are endowed with large natural deposits of gypsum. Furthermore, there are no gypsum reserves on the eastern seaboard of the United States and large imports from Canada increase the domestic supply in these industrial demand regions.

Gypsum in Agriculture

Gypsum, a low cost and high tonnage commodity, competes with other building materials. Large gypsum mines and integrated plants have fostered a stable gypsum price for many years (Reed). Processing of crude gypsum affects its price, and the degree of processing depends on the end use. For use in cement, gypsum is crushed to minus half inch. For use in agriculture or filler, it is ground to about 100 mesh.

In agriculture, finely ground gypsum is used to neutralize alkaline and saline soils, provide sulfur, improve water permeability of crusting soils, and enhance fertilizer use and crop yields, particularly for leguminous crops. Moreover, gypsum has been used to improve physical properties of dispersive soils and chemical properties of acid soils, and reclaim sodic soils. On crusting soils, gypsum has high potential for improving water use efficiency and product quality. On acid soils, gypsum application alone proved to be a short term solution to limitations in production.

In industrial countries with supply of cheap by-product gypsum, intensive agronomic research programs, and readily available credit, gypsum use may well expand, especially on ultisols where crusting and subsoil acidity are both yield limiting (FGD and DeNOx Newsletter, 1993). In 1991, 37 percent of the uncalcined gypsum was used in agriculture. Potential agricultural benefits from FGD by-product gypsum include alleviating soil trace elemental deficiencies, and the need to increase calcium and sulfur (Makansi). Table 2 summarizes the trace element concentration ranges in the wet FGD solids and liquors. Boron, Cu and Se may be considered beneficial nutrients if applied at appropriate rates, whereas, As, Cd, Cr, F, Hg and Pb are usually considered not to be beneficial, and in fact, harmful if they accumulate in soils or plants.

PART II. ECONOMIC ANALYSIS

Introduction

The purpose of this analysis is to provide, on a national basis, estimates of market forces affecting gypsum utilization in agriculture. This analysis provides perspective on the potential use of coal combustion (FGD) by-product gypsum in agriculture. Specifically, the demand and supply relationships of by-product gypsum and the factors affecting the variations in its use in agriculture are estimated. The demand relationship mirrors all the variations of the by-product gypsum usage as external factors vary. In the case of this study, external factors affecting demand for agricultural by-product gypsum are the price of the by-product gypsum, prices involving agricultural production such as fertilizers, price of crops, and other indirect factors such as the variations in net farm income. On the other hand, supply is the relationship between production and the price of by-product gypsum and exogenous variables. Exogenous variables include the price of all industrial and manufactured gypsum and the cost of production factors such as fuels and transportation costs. The price of gypsum used in construction (crude and wallboard), which is probably the second leading option for FGD gypsum after agriculture, is also assumed to affect the supply and demand of by-product gypsum.

Consumption of gypsum in the United States is a function of total U.S. production, total U.S. net imports, and the industry stock change. It is assumed, for the purpose of this study, that consumption and demand are the same due to the fact that no imports gypsum by-products are used in agriculture.

Data collection

Data entering into the estimation of consumption demand and supply relationships of agricultural gypsum (including by-product gypsum) consists of:

- Prices (in dollars per ton) of crude and by-product gypsum as well as quantities (in 10^3 tons) of by-product gypsum (agricultural gypsum) were obtained from the Bureau of Mines, US Department of the

Interior, Pittsburgh, Pennsylvania.

- Quantities of agricultural gypsum used were collected from the Minerals yearbook series from 1956 to 1991.
- Prices and quantities of gypsum (industrial, prefabricated and used in building) were collected from the Minerals Yearbook series. Prices were computed on an average basis of the value of the total production and use in the United States.
- The index of farm input use related to prices paid by farmers for fertilizers and the U.S. net farm income (in million dollars) were obtained from the Economic Report of the President, Council of Economic Advisers, Annual Report of 1991.
- The producer price index for intermediate materials for manufacturing including fuels and transportation were collected from the Economic Report of the President, Council of Economic Advisers, Annual Report of 1991.

Since all gypsum products considered in the study are used as intermediate goods in production processes, all prices are deflated by the producer price index for intermediate goods with 1982 being the base year. US net farm income is deflated by the GDP implicit price deflator (Department of Commerce) beginning from 1959 since the deflator was not yet available prior to 1959.

Method of Estimation

Two methods were used to estimate the demand and supply relationships. One is of double log-linear form using both Ordinary Least Squares (OLS) and Two Stage Least Square (TSLS) regression techniques. The second is a regular linear regression using OLS and TSLS estimation methods. Comparing these procedures, the double-log linear regression estimations provide more interesting results. Furthermore, the TSLS provides better parameter estimates than does OLS. A detailed comparison of the results obtained with single equations OLS and the simultaneous equations system TSLS is presented in Tables 3 through 6.

Results

From the results of both functional forms, using the same estimation technique, the log-linear model has more reliable coefficient estimates. The equations that best explain the present study's objective related to demand and supply characteristics of agricultural by-product gypsum are, therefore, the following:

Demand and Supply Estimates

Demand Equation

$$\log(QBG) = 4.51 - \underset{(-0.111)}{0.013 \log(PBG)} + \underset{(3.075)}{0.353 \log(IPPFF)} + \underset{(2.508)}{0.317 \log(NFINC)}$$

$R^2 = 0.40$ and Adjusted $R^2 = 0.34$

Supply Equation

$$\log(QBG) = 3.42 + \underset{(1.905)}{1.058 \log(PBG)} - \underset{(-0.487)}{0.325 \log(PCR)} - \underset{(-3.066)}{2.067 \text{Log}(PBLG)}$$

$$+ \underset{(2.095)}{0.939 \log(PRE)} - \underset{(-0.032)}{0.018 \log(IF)} + \underset{(2.335)}{1.65 \log(TR)}$$

$R^2 = 0.44$ and Adjusted $R^2 = 0.29$

wherein

The number in parenthesis is the t-statistic
QBG = quantity of agricultural byproduct gypsum
PBG = real price of agricultural byproduct gypsum
IPPFF= index of price paid by farmers for fertilizer
NFINC = net farm income
PCR = real price of crude gypsum
PBLG = real price for cementeous gypsum
PRE = real price for prefabricated gypsum
IF = index of price of fuel
TR = index of price for transportation costs

The equations above are the estimated demand and supply relationships. They identify the contribution of each single factor in explaining the variations in the quantity of agricultural by-product gypsum sold for agricultural purposes in case of demand, or produced in case of supply holding all other variables constant.

The coefficients of determination (R^2) in both supply and demand side are not high, 0.44 and 0.40 respectively. That is, 44 percent of variation in supply and 40 percent of the variation in demand are explained by those factors hypothesized to influence supply and demand of by-product gypsum. In terms of individual parameters, the demand price elasticity of agricultural gypsum is shown to be inelastic (-0.013) and is statistically insignificant. Inelasticity implies that demand is relatively insensitive to price changes. The response to a 1 percent increase in gypsum price is a decrease of 0.013 percent in quantity demanded by farmers. Gypsum use in agriculture proves to be income inelastic (0.317) with high coefficient estimate and positive response to income variations. Similarly, gypsum demand is positively related to the price paid for fertilizer but characterized with inelastic response (0.353). That is, an increase in the price of fertilizers by 1 percent results in a switch to gypsum use that increases demand of agricultural gypsum by 0.317 percent holding everything else constant. In summary, with other factors held constant, a 1 percent increase in net farm income increases quantity demanded by 0.317 percent, a 1 percent increase in fertilizer's price increases quantity demanded of agricultural gypsum by 0.353 percent, while a 1 percent increase in agricultural gypsum price reduces gypsum application by 0.013 percent.

In case of supply side of agricultural gypsum, the estimated equation indicates an elastic price elasticity of agricultural gypsum (1.058). That is, gypsum producers respond to a 1 percent increase in agricultural gypsum price by an increase in supply of 1.058 percent, ceteris paribus. An inverse relationship, though, is between prices of crude and calcined gypsum used in construction and the supply of gypsum used in agriculture. That is, increased use of gypsum in construction reduces supplies available for agriculture. If we consider production factors, a one percent increase in cost of fuel leads to a drop of 0.018 percent in gypsum supply for agricultural use. However, one percent increase in the price of prefabricated gypsum and transportation increases agricultural gypsum by respectively 0.939 and 1.65 percent, which may be explained by the fact that an increase in the prefabricated products leads to the generation of more by-product gypsum that can be used in agriculture. The positive relationship between the transportation costs and agricultural gypsum supply is unexpected. However, it may be explained by the decreased use of gypsum in the construction and building industry as transportation costs increases. Thus, gypsum stocks increase leading to more available supply of agricultural gypsum.

Summary and Implications

The need to reduce sulfur emission from high sulfur coal combustion in generating electricity, imposed by the United States' clean air laws, results in large volumes of by-products. Gypsum, produced as an FGD by-product, is a material composed of similar compound as that of crude gypsum except for some trace elements of primary process. It is suitable for agricultural use and its composition is not considered as an environmental threat, i.e. leading to contamination or damage of surface or groundwater.

Recent environmental policy in industrial countries is to encourage recycling or recovery of the non hazardous wastes. Gypsum can efficiently deal with saline and alkaline soils. Moreover, it provides sulfur, enhances the permeability of crusting soils, and improves crops yields. Large amounts of potentially useful by-product gypsum is produced by FGD scrubbing systems, of which, only a small amount is being recovered (Korcak). In addition to agriculture, FGD gypsum has the potential to be used as a source of sulfur in the production of chemical fertilizers and to promote exports to countries short of sulfur-equivalent fertilizers. If most of the power plants generating electricity from coal combustion use the forced oxidation method, better quality gypsum could be produced and sold as a substitute for crude gypsum in wallboard and cement industries.

The objective of this study is to estimate demand and supply relationships for agricultural gypsum in the United States in order to provide perspective on the potential use of FGD gypsum for agricultural purposes. The result of the econometric analysis indicates that the demand price elasticity and the supply price elasticity of agricultural gypsum are -0.013 and 1.058 respectively. In terms of supply price elasticity, the model provides an explanation of the wide availability of gypsum in the United States, whereas, demand is highly inelastic with respect to agricultural gypsum price change indicating a relatively stable demand of gypsum in agriculture. If FGD by-product gypsum enters the agricultural gypsum market, it will increase supplies and decrease agricultural gypsum prices. However, it will have little effect on the total use of agricultural gypsum from all sources. Factors that would enhance the use of agricultural gypsum are increase in net farm income and the price of fertilizers.

By-product gypsum from FGD is a part of the nonphosphogypsum products, and the recent trend in the use of nonphosphogypsum products points to increased demand for other FGD gypsum products, such as wallboard. The United States' production of FGD gypsum from coal combustion could feed the wallboard industry if more attention is given to advanced processing and if the cost of advanced processing is more efficient in producing wallboard compared to that produced from natural gypsum.

Table 1: Past, present, and projected amounts of by-products produced by the coal combustion industry.

By-product Type	Production (Million Ton)		
	Past 1984	Present 1991	Projected (2000)
Ash			
Fly	-	51.3	86
Bottom	-	12.3	29
Total*	69	70.07	120
FGD	16	18	50

*Includes boiler slag.
Source:U.S.EPA, 1988; American Coal Ash Association. Washington,D.C. Cited in Industrial Report, USDA. unpublished report.

Table 2: Trace element concentration range in wet FGD solids and liquors. (Values are in parts per million)

Element	Solids	Liquors
Essential plant & animal nutrient		
-Boron	42-530	2-76
-Copper	6-340	<0.01-0.5
-Selenium	2-60	<0.01-1.9
Other elements		
-Arsenic	0.8-52	<0.01-0.1
-Cadmium	0.1-25	<0.01-0.1
-Chromium	1.6-180	<0.01-0.3
-Fluoride	266-1017	0.2-63
-Mercury	0.01-6	<0.01-0.1
-Lead	0.2-290	<0.01-0.5

Source: U.S.EPA, 1988. Cited in Industrial Report, USDA. Unpublished report.

Table 3. OLS Estimation of The Supply Model for Agricultural by-product gypsum (1956-1991)

Explanatory variables	Linear	Double-Log
Intercept	3484.00 (3.531)	10.810 (3.277)
Price of agricultural gypsum	-16.809 (-0.561)	-0.056 (-0.180)
Price of crude gypsum	-210.72 (-3.218)	-1.184 (-2.292)
Price cementious gypsum	-25.49 (-3.571)	-2.172 (-3.702)
Price prefabricated gypsum	7.99 (1.904)	0.586 (1.661)
Index for fuel	15.46 (3.665)	1.166 (3.548)
Index of transport-ation costs	-5.18 (-0.743)	0.139 (0.326)
R-square	0.56	0.54
Adjusted R-square	0.46	0.44

OLS = Ordinary Least Squares.
't' values are indicated in the parenthesis.

Table 4. TSLS Estimation of The Supply Model for Agricultural by-product gypsum (1956-1991)

Explanatory variables	Linear	Double-Log
Intercept	4574.66 (0.926)	3.429 (0.661)
Price of agricultural gypsum	-27.02 (-0.155)	1.058 (1.905)
Price of crude gypsum	-229.79 (-1.727)	-0.325 (-0.487)
Price cementious gypsum	-27.15 (-2.829)	-2.067 (-3.066)
Price prefabricated gypsum	6.965 (0.834)	0.939 (2.095)
Index for fuel	7.66 (1.451)	-0.018 (-0.032)
Index of transportation costs	-0.67 (-0.023)	1.65 (2.335)
R-square	0.57	0.43
Adjusted R-square	0.46	0.28

TSLS = Two Stage Least Squares.
't' values are indicated in the parenthesis.

Table 5. OLS Estimation of The Demand Model for Agricultural by-product gypsum (1956-1991)

Explanatory variables	Linear	Double-Log
Intercept	743.523 (2.015)	5.028 (5.618)
Price of agricultural gypsum	-21.604 (-1.186)	-0.107 (-1.048)
Index of price paid for fertilizer	4.313 (2.587)	0.194 (2.857)
Net farm income	11.629 (2.711)	0.307 (2.515)
R-square	0.41	0.43
Adjusted R-square	0.35	0.37

OLS = Ordinary Least Squares.
't' values are indicated in the parenthesis.

Table 6. TSLS Estimation of The Demand Model for Agricultural by-product gypsum (1956-1991)

Explanatory variables	Linear	Double-Log
Intercept	826.43 (2.058)	4.517 (4.561)
Price of agricultural gypsum	-27.43 (-1.291)	-0.013 (-0.111)
Index of price paid for fertilizer	3.742 (1.971)	0.353 (3.075)
Net farm income	11.68 (2.628)	0.317 (2.508)
R-square	0.39	0.40
Adjusted R-square	0.32	0.34

TSLS = Ordinary Least Squares.
't' values are indicated in the parenthesis.

Table 7. Gypsum production, thousand tons and dollar per ton

Year	Crude gypsum			Agricultural gypsum		
	Quantity	price		Quantity	Price	
		Actual	Real		Actual	Real
1956	10,316	3.31	11.18	830	3.77	12.74
1957	9,195	3.25	10.73	831	3.75	12.38
1958	9,600	3.38	11.12	1,021	3.30	10.85
1959	10,900	3.59	11.56	1,188	3.01	10.03
1960	9,825	3.63	11.78	1,126	3.29	10.68
1961	9,500	3.68	12.03	1,088	3.50	11.44
1962	9,969	3.65	11.93	1,241	3.40	11.11
1963	10,388	3.67	11.99	1,262	3.46	11.27
1964	10,684	3.64	11.82	1,475	3.74	12.14
1965	10,033	3.73	11.95	1,359	3.51	11.25
1966	9,647	3.70	11.56	1,240	4.20	13.12
1967	9,393	3.66	11.37	1,280	4.27	13.26
1968	10,018	3.67	11.12	1,388	4.48	13.57
1969	9,905	3.88	11.38	1,100	4.48	13.57
1970	9,436	3.72	10.51	804	5.27	14.89
1971	10,418	3.75	10.19	1,124	4.80	13.04
1972	12,328	3.93	10.29	1,146	5.11	13.38
1973	13,558	4.18	9.86	1,453	6.00	14.15
1974	11,999	4.14	7.88	1,671	9.29	17.69
1975	9,751	4.58	7.89	1,482	7.96	12.57
1976	11,980	5.00	8.21	1,714	7.36	12.08
1977	13,390	5.55	8.55	1,675	8.04	12.39
1978	14,891	6.23	8.96	1,508	6.46	9.55
1979	14,630	6.83	8.71	1,700	6.05	7.72
1980	12,376	8.33	9.22	1,658	8.56	9.48
1981	11,497	8.53	8.65	1,525	9.42	9.55
1982	10,538	8.46	8.46	1,301	7.90	9.70
1983	12,884	7.87	7.82	1,309	9.39	9.33
1984	14,319	7.94	7.70	1,326	8.30	8.05
1985	14,414	7.76	7.55	1,180	7.70	7.50
1986	15,403	6.46	6.52	943	7.12	7.18
1987	15,612	6.85	6.75	1,330	6.48	6.38
1988	16,390	6.66	6.22	1.388	8.93	8.34
1989	17,624	7.29	6.51	2,094	4.03	3.60
1990	16,406	6.07	5.30	2,099	4.27	3.73
1991	15,456	6.09	5.32	1,890	4.49	3.92

Source: L.J.Prossser, Jr. US Department of the Interior. Bureau of Mines. Pittsburgh, PA.

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